ON THE MODELLING OF SEAPOWER
An Extension of the Polis Model in a Competitive Scenario[1]

M.Piattelli and R.G.Coyle[2]

C.N.R. - Istituto per l'Automazione Navale
via De Marini, 6 - 16149 Genova, Italy
fax: +39 10 6475 600
e-mail: polis@ian.ge.cnr.it

0. Abstract

This paper deals with an extension of the "Polis" model that focuses on the subject of Sea Power.

The presentation follows two complementary lines: the simulation of the naval conflict arising from Greek colonization westward during the last millennium BC; the discussion of this model within the general approach to Sea Power adopted by the leading authors in the field, Mahan and Kennedy.

The conclusions concern the actual limits of the Polis in modelling Sea Power and further steps in its development. Finally, the main difficulties involved in issues of this kind are briefly discussed.

1. Introduction

1.1. Sea Power

The concept of Sea Power appears to be intuitive and refers to a process that can undoubtedly be considered as the output of a Dynamic System. Interest in this concept lies in two main areas: the key role Sea Power plays in historical analysis and its possible application in support of decision making.

The importance of Sea Power as compared with other power factors derives from the simple consideration that three-quarters of the Earth's surface is covered by sea-water.

However, difficulties arise when seeking to model Sea Power: the numerous aspects characterizing a nation (the subject of sea power) including geographical, demographic, social, economic, political and technological matters; interaction with other countries that play a role in a given scenario; and the possible or actual strategy adopted by subjects in order to reach their specific targets.

One further problem concerns the effect of ideas and theories, a factor that commonly plays a role in processes linked to human behavior; even if a theory or idea is not actually "true", it can produce real effects because a significant number of people believe in it. Magic is one example of this phenomenon (Mauss 1950), but policies and strategies often appear to fall into the same

[1] The authors gratefully acknowledge the contribution provided by M. Cuneo (IAN-CNR) and N. Bianchi (CSST-CNR) to the design and implementation of the research which forms the basis of this article.

[2] R.G. Coyle is professor of defence strategic analysis at the Royal Military College of Science, Shrivenham, Swindon, Wilts SN6 8LA, England.

category. In terms of System Dynamics, this means that unexpected feedback from historical interpretation affects the future process.

Therefore, let us freely quote a previous paper (Coyle 1989): "there are no doubts that the role of any analyst in approaching strategic modeling problems should be characterized by modesty. To pretend, or even to believe, that one can provide definitive answers to such a broad question would be almost folly. The best that can be hoped for is to support other thinking and to try to add clarity to what is, at best, a very cloudy area."

1.2. The Polis Model and Sea Power

The Polis model (Piattelli *et al.* 1994) was received with interest at the Stirling conference and one idea that occurred to the authors of this paper was to collaborate on the development of the model as a tool for exploring the issue of Sea Power.

The Polis model would appear to be a suitable starting point in this respect as it offers certain advantages:

- it is reasonably large, i.e. it can handle a sufficient number of variables to cover any historical period and therefore also the future;
- in simulating city-states (or nations) with some connection to the sea, it takes into account a considerable number of characterization elements , including cultural aspects;
- it concerns historically distant events that are sufficiently well known for the model to be set in a real scenario, but not so detailed that interpretation loses generality.

Keeping in mind the earlier statement about modesty, the authors propose the Polis model as a first step in approaching the issue of Sea Power. The present version of the model deals with conflict at sea caused by Greek colonization from around 850 to 550 BC and the reaction to this by Phoenician and Etruscan Polises in order to maintain their areas of influence.

1.3. Adjustment and Extension of the Polis Model[3]

The improvements made to the model in order to deal with Sea Power are as follows:

- a certain number of Polis models (five in this case) can be run simultaneously so that they may be used in the conflicts;
- a further Polis characteristic splits trade into on-shore and offshore activities;
- the naval fleet is made up of line and auxiliary vessels; the number of the former is treated as a state variable (main level) by a new "Arsenal" subsystem;
- the initialization of a new colony is introduced, converting migration data into the birth of a new Polis; this process is then tracked by the model;
- a sort of Delphic Oracle has been adopted to define the site of a new Greek colony in terms of a potential enemy Polise;
- the effects of a new colony on the mother Polis are examined in detail and the impact on an enemy Polis, which causes the conflict, has been introduced;
- the outcome of conflict is determined by the respective number of line vessels deployed, according to certain strategies and adjustments;
- conflict affects population, vessel numbers and economic conditions, all of which are computed by the last of the model's new blocks.

1.4. Further Introductory Considerations

This paper describes the main facets of the features listed above. Then the concept of Sea Power is introduced with a quotation by A.T. Mahan (1890), who is considered to be the father of the

[3]There is insufficient space here to summarize the main features of the model presented at the Stirling conference. Detailed documentation will be available at the conference.

modern approach to this subject and the criticism his work has received from practically every subsequent author would appear to confirm his importance. Only P. Kennedy (1987), the latest modern-day critic, has had as much impact on public opinion.

The model presented is examined in terms of the principles expressed by the above authors and the conclusion concerns its limits as well as further steps in its development.

The Polis model and the recent upgrade described here have been written using MATLAB. Following the acceptance of COSMIC for further model development, work on the corresponding versions is underway and should be available at the conference time.

2. Main Features of the Model

2.1. Conceptual Interpretation

Two Greek Polises are considered, both of which are capable of establishing colonies[4] in areas eventually controlled by either a Phoenician or Etruscan Polis. This appears to be but a small fraction of the whole scenario and is somewhat limited from the historical point of view, largely because there were more Greek mother Polises than potential enemy ones. However, the introduction of two different characterizations for both Greek and enemy Polises is provided.

The Delphic Oracle declares the site for each new colony: if the previous colony has survived, the same area is chosen, otherwise a new location is selected. In addition, if three consecutive colonies have been lost, the next site chosen will be far away from enemies - as in the case of the model's first Greek colony.

Completion of a Greek migration results in the birth of a new Polis, the fifth in the model. This is tracked until possible conflict is over or abandoned.[5]

The creation of a new colony brings about a crisis, which is eventually resolved two years later by a naval battle on the colony's site. The enemy Polis withdraws from the war if the fleet it manages to rig for the battle is smaller than that belonging to the colony. Where battle is undertaken, uncertainty about the outcome derives from assistance given to the colony by the mother Polis, together with adjustment of actual power.

In any case, conflict is limited to the survival or otherwise of the colony and does not involve a direct clash between mother and enemy city-states with the aim of reciprocal destruction.

2.2. The Arsenal Subsystem

Actual military power (warriors engaged each year) is assigned to on-shore and offshore activities according to the value of corresponding trade[6].

The fleet is manned by sea warriors and consists of equal numbers of line vessels (60-man crew)[7] and auxiliary vessels (25-man crew). The number of line vessels is treated as a main level.

If the number of vessels required exceeds those available, the shortfall is met by new vessel construction and the related cost is added to war expenses. On the other hand, excess vessels are held in reserve and a percentage is scrapped each year. During migrations, excess vessels are assigned to the colony and the reserve is void. Conflict always requires new vessel construction.

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[4]Panhellenic colonies established by more than one Polis together are not considered.

[5]Such single fifth channel or Cosmic sector is sufficient for all Greek colonies because only two mother Polises are simulated and therefore only one colony is to be tracked at any given time.

[6]The Polis model considers war as a complementary activity to trade. Warriors are exclusively free men.

[7]Two-banked or single-banked war galley manned by 50 oarsmen.

2.3. Actual Power of Fleets Engaged in Conflict

The colony deploys 80% of its operating vessels in conflict (the remainder is assumed to be far away, in support of trade) plus any additional vessels it manages to man with the warriors available (demographic ceiling).

Similarly, the enemy Polis assigns 10% of its operating vessels to conflict (5% is already deployed in curbing the activities of the colony, while the remainder is assumed to be in the vicinity), plus any additional amount up to its ceiling until an advantage is reached.

The mother Polis deploys a back-up fleet which is smaller than the colony's and below its own ceiling. Assistance is more substantial if the previous Greek colony has been lost.

This interpretation takes into account the fact that for the colony the conflict is a matter of survival, while the other participants see it mainly as a matter of trade . Therefore, even when the mother and enemy Polises are involved in conflict, they continue to engage in warfare elsewhere to support trade.

Following calculation of the fleets, their actual power is adjusted according to two factors:

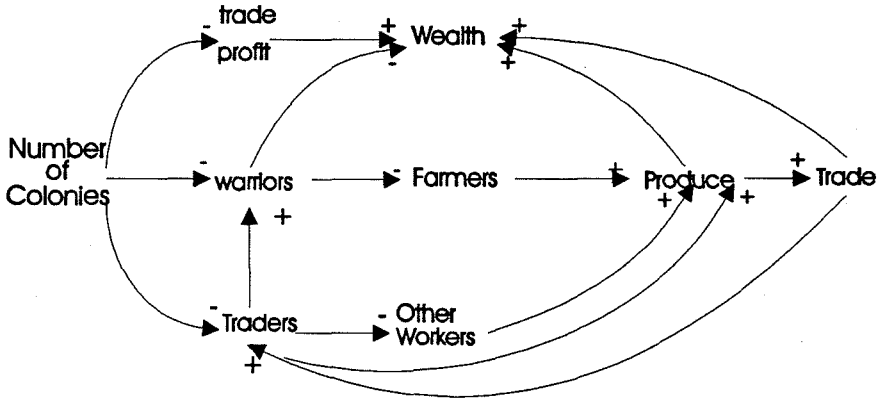
- crew experience, which depends on the average number of battles per year
- technology, expressed by the economic value of per capita non-food production.

The comparison of vessel numbers, corrected by these two factors, provides conflict outcome.

2.4. The Impact of New Colonies

The influence diagram below illustrates the impact of a new colony on the mother Polis.

Roughly speaking, there is an immediate reduction in wealth resulting from the share in trade profits assigned to the new colony. In the longer term, however, the level of wealth rises as a result of two factors: the increased number of workers, a condition brought about by lower war and trade mortality; and a reduction in war expenses.



Influence diagram illustrating the effects of colony numbers on the mother Polis.

The effect on the enemy Polis' traders is ignored while the impact on its warriors is positive; wealth is reduced both by short and long-term effects.

2.5 Effects of Conflict Outcome

Losses of both warriors and vessels are calculated at 5% in the case of victory and 14% for defeat. The loser suffers a further 9% loss in enslaved warriors and vessels seized by the victor.

The defeated Polis covers conflict costs with savings, slaves belonging to the Lords and by employing public savings, while the victor sells the necessary share of new slaves.

If the enemy Polis is the victor, it takes possession of the colony by forcing a small number of its own Polis inhabitants to migrate.

The Etruscan Polis is of particular interest because of its generality. It is assumed that 70% of its initial trade is offshore and this figure rises or falls according to conflict outcome.

3. Sea Power

3.1. The Thoughts of Mahan and Kennedy's Criticism.

Let us quote directly from Chapter 1 of Mahan: "In these three things (production, with the necessity of exchanging products; shipping, whereby the exchange is carried on; and colonies, which facilitate and enlarge the operation of shipping and tend to protect it by multiplying the points of safety) is to be found the key to much of the history, as well as of the policy, of nations bordering upon the sea."

"The necessity of a navy .... springs from the existence of a peaceful shipping, and disappears with it, except in the case of a nation which has aggressive tendencies...".

"The principal conditions affecting the sea power of nations may be enumerated as follows: 1. geographical position; 2. physical configuration, including natural production and climate; 3. extent of territory; 4. number of population; 5. character of the people; 6. character of the government."

One criticism levelled at Mahan relates to his (and other authors') use of the argument to justify a policy of naval aggression. The objections of some critics such as Kennedy are more conceptual in nature and may be summed up in this way: Sea Power cannot be treated as an isolated factor; it is but one component of the overall power of a nation. Considering military power means taking into account not just the army, navy and (today) airforce, but also other aspects, principally economic, social, technological and political factors, all of which may contribute to power in a complementary or even conclusive way.

One element which typically causes a great power to fall is territorial overextension, a factor which must be kept under control. In any case, a nation's power only becomes significant when compared to that of other countries which play a role in the same scenario.

That being said, we must recognize that history comprises a series of exceptions to, rather than proofs of, general rules. Nevertheless, we can assume some statements to be generally true.

The concept of power does not embody a single invariant meaning, as each civilization has its own particular targets. Power results from a combination of different factors which vary both in role and importance.

However, this concept appears to be too general for the purposes of this work. Let us restrict the focus to military matters, where two significant situations can be identified:

- The outcome of a brief war depends on a limited number of power factors, such as Sea Power and its facets, instructional level, crew experience, current technology and so on.
- On the contrary, the outcome of a protracted war depends on quantitative ceiling factors such as population level, territorial extension, abundance of raw materials, production, wealth in all its facets, etc.

Sparta's victory in the Peloponnesian War, for instance, can be easily explained by just two factors: the league's population level and the economic support it received from the Persian

Empire. At the war's outset, Sparta had no Sea Power at all but by the end its navy was the only one in the area.

3.2. Sea Power and The Polis Model

The arguments raised in the previous paragraph go beyond the scope of the initial approach to Sea Power contained in the Polis model.

Aggressive or imperialistic policies are not considered and so there are no global wars involving large alliances. War and conflict are short-term seasonal events and conflict is restricted to the resolution of its cause, i.e. the birth of a new colony. The colony is not an extension of the motherland but a new independent Polis. Therefore it is neither a base, as held by Mahan, nor a territorial enlargement, which is seen by Kennedy as a fundamental risk.

Bearing these limitations in mind, let us consider the Polis model in the light of arguments put forward by these two authors.

- Mahan proposes the causal connection of surplus/trade/shipping/navy but history points to other connections as well: non-surplus to navy (Rhodes in 300 BC, the Maritime Republic of Genoa), and no shipping of its own (ancient Rome and post-war USA). The Polis model directly links military power with the volume of trade, to which third parties can contribute.
- geographical position. The Polises considered are those located on the coast, which are not induced toward territorial expansion either by land or by sea. New colonies are forced to defend themselves at sea.
- physical configuration. A parameter sets the share of trade conducted by sea. Climate and natural production can be set by the initial values of per capita food production according to soil fertility, and of non-food production according to abundance of raw materials.
- territorial extension. The limit of productive land is introduced. Greek Polises, with the exception of Athens and Sparta, were very small, as were Phoenician Polises, excluding Carthage. The opposite is true of the Etruscan city-states, which never suffered from insufficient food production.
- population level. The Polis model includes the dynamics of four classes of population, a range which adequately covers all the population aspects examined by both Mahan and Kennedy. Possible outputs include: free population and slaves; total workers; farmers expressed as freemen and slaves; ditto for other workers; traders; total warriors; sea warriors.
- national character. The Polis includes some cultural factors which set propensity to trade and the dominant classes' self-preservation capacity, which affects wealth distribution.
- character of the government. All city-states are controlled by an oligarchy of lords whose aim is to maintain power over the Polis. Migration is regarded as a tool for avoiding the social conflict that arises from expansion of the emerging class.

The above elements are those enumerated by Mahan. In addition, we consider:

- military power as a whole (the model includes both army and navy);
- economic factors. Workers and per-capita production have already been considered, while additional factors include: a) public savings; b) private savings of the dominant classes; c) gross and net national product; level of trade.
- technological level and crew experience are explicitly introduced but not instructional level.
- diplomacy. This is assumed to constitute a tool for avoiding conflict between city-states that belong to the same cultural world. Examples of this can be seen in the role played by the Delphic Oracle[8] in the Greek world and that of the Fanum Voltumni in the Etruscan domain.

[8] It must be remembered that Etruscan Caere has its own treasure at Delphi, therefore this Oracle was also an international centre of diplomacy.

4. Explicative Outputs

For reference, output plots are contained in the Appendix. There are 4 Polises: Greek A and B, Phoenician and Etruscan, whose initial data as well as some characteristics are assumed to be alike, while differing parameters are shown in Table 1.

	Ashore Trade	Trade Attitude	Trade Time	Trade Morts	Wealth factors	
					Lords	Em. Class
Greek A	30%	.25	2	5	30	10
Grrek B	5%	.5	2	7	30	23
Phoenician	5%	.55	6	21	50	42
Etruscan	30%	.55	6	14	50	42

Table 1: Parameters for the polises characterization.

Colonies maintain the characteristics of the mother Polis but with a greater propensity to trade and more extensive productive land.

In table 2, the conflicts that occurred in the 500-year simulation period are summarized.

Colony Birth Year	Mother Polis	Enemy Polis	Conflict Yes/No	Victorious Polis	Line Vessels		
					Colony	Mother	Enemy
121	Greek B		NO				
159	B	Phoen.	YES	Phoen.	3	2	5
162	Etrus.		NO				
197	B	Etrus	YES	Etrus.	4	2	7
206	Phoen.		NO				
220	Etrus.		NO				
226	Greek A	Phoen.	YES	Phoen.	5	3	8
236	B		NO				
263	B	Phoen.	YES	Phoen.	3	2	6
266	A	Etrus.	YES	Etrus.	5	3	9
293	B	Phoen.	YES	Phoen.	4	2	6
305	A		NO				
328	B	Phoen.	YES	Phoen.	4	2	7
357	A	Etrus.	NO		9		3
366	B	Phoen.	NO		5		4
419	A	Etrus.	NO		13		4
423	B	Phoen.	NO		6		4
491	A	Etrus.	NO		18		5
Greek A Polis:	total migration number = 6		total colonies survived = 4				
Greek B Polis:	total migration number = 9		total colonies survived = 4				
Phoen. Polis:	total migration number = 1		total colonies conquered = 5				
Etruscan Polis	total migration number = 2		total colonies conquered = 2				
Total number of conflicts = 7							

Table 2 : Colonial conflicts and their conclusions.

The plots in the Appendix have been chosen with an eye to comparing some factors related to power.

The first three are shown in relative mode, i.e. each Polis/sum of all Polises without colonies:

Fig.1 number of workers, expressed as free productive population plus corresponding slaves;
Fig.2. size of free population (states the ceiling for the number of warriors);
Fig.3 public savings (*Valpol*);
The rest are presented in absolute mode:
Fig.4 number of line vessels engaged in seasonal warfare;
Fig.5 maximum number of line vessels which may be rigged;
Fig.6 per-capita production factor (*variu*) for non-food production, which is also assumed to be an indicator of technological level[9].

4.1. Comments on Table 2

While the Polis models are not tuned to documented historical cases, some historical aspects can be explained by the simple example examined in this work. Regarding Sea Power, line vessels crewed by 50 oarsmen should only be introduced after the first century, as until that time there are insufficient sea warriors to man the number of vessels required to meet operational needs (see also Plots Fig.4). In other words, the dynamics of naval vessel type should be considered.

In respect of conflict outcome, the table reveals two different periods. During the first, the Greek colonies are always conquered because they are too small (population ceiling) and assistance from the mother Polis is limited (strategic factor). During the second, all the colonies survive because the enemy Polises cannot rig extra vessels for battle. These Polises suffer from excessive military engagement in support of trade (population ceiling) and do not devote powerful enough fleets to destroy the colonies (strategy factor). This situation corresponds to that described by Kennedy where the territory is too large to be controlled. Historically, the problem is solved by appropriate alliances[10].

4.2. Comments on the Output Plots

The plots in the Appendix demonstrate some power factors and the general problem arises of finding a scalar quantity to associate to the vector of the factors as a significant gauge[11]. This problem typically arises when gauging the power of nations, sea power, the quality of life and so on. Each factor can be compared directly and there is no doubt that the best nation has the highest figures. However, in general, the factors must be converted into suitable homogeneous quantities and weighted before a significant comparison can be obtained[12].

According to the simple example proposed, economic factors are indecisive in conflict because this is a short-term event (one month in the model in order to calculate the corresponding cost). Nevertheless, conflict does alter Polis evolution, as demonstrated by a comparison of the runs with and without it. This is not commented upon here as the latter situation is historically unlikely.

When the authors conceived this work, it seemed possible to use the recent growth of the Indian Navy as an example. This can be summed up in a few words by comparing trends in military expansion and GNP; to examine the issue in greater detail, we must consider the targets of

[9] The example features the same initial value for *variu*, i.e. equal levels of raw materials.

[10] Herodotus states that the naval battle of Alalia (535 BC) was won by the allied fleet provided by Etruscan Caere and Carthage against the last colony from Greek Phocaea.

[11] The norm of a state vector, i.e. its length, does not set a bi-univocal correspondence between the scalar gauge of energy and its real content in the system.

[12] In any case, this comparison is only significant for the subject, whose factors and weights are stated. It would appear that, as in the case of the quality of life, a universal scale cannot be set owing to the role of cultural factors.

the Indian nation and all significant factors related to the issue, and must make a comparison with its major neighbours, particularly China and Pakistan. However, the first method is not overly useful while the second would require an entire study in itself.

5. Conclusions

One fundamental element in the work of all the authors who have examined Sea Power concerns the invariance throughout history of strategic principles, while technological progress and other complementary factors merely bring about tactical change.

In this respect, the Polis model appears to focus too closely on a certain period and scenario, and in the author's opinion must be revised to obtain a simplified version. This would satisfactorily deal with the strategic principles, and would also take into account all the parameters that allow simulation in a real scenario, possibly in the form of outputs from software interfaces for tuning the model.

A revision of this kind would redefine the variables in order to obtain strict correspondence with those that are now standard in social, economic and defence matters. Furthermore, this simplification would be helpful in increasing the number of Polises (or nations) which can run synchronously without losing control of the model.

That being said, even when interest is focused on Sea Power, the present version has several limitations, which mainly concern the lack of internal dynamics within significant factors:

- combat capability depends on the number of vessels but also on their type; innovation in line vessel type and, generally speaking, in weapons shall be introduced;
- transport capability depends on the number and size of merchant ships, therefore both such variables shall be introduced as levels;
- number and strategic site of the bases shall be introduced, both as significant variables and dynamics.

The above list concerns steps which are now under consideration in the development of the model, which seems to have the potential for general application in the field of Sea Power. The gauging or quantification of Sea Power represents a more general question that remains to be solved.

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7. Appendix

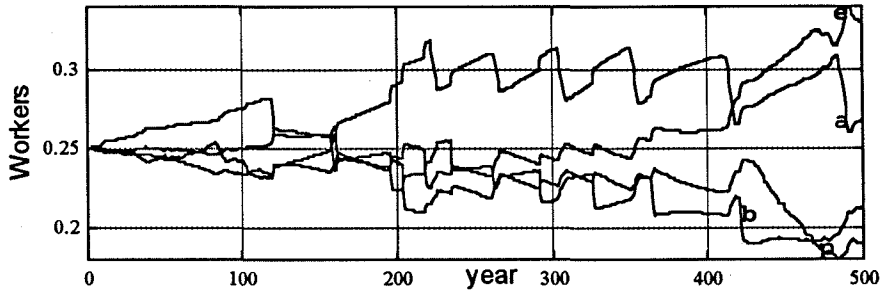

Fig.1

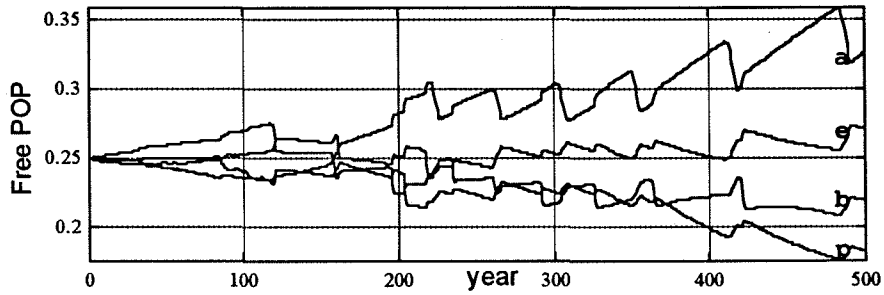

Fig.2

Fig.1: number of workers. (a=Greek A, b=Greek B.p=Phoenician, e=Etruscan)
Fig.2: size of free population.

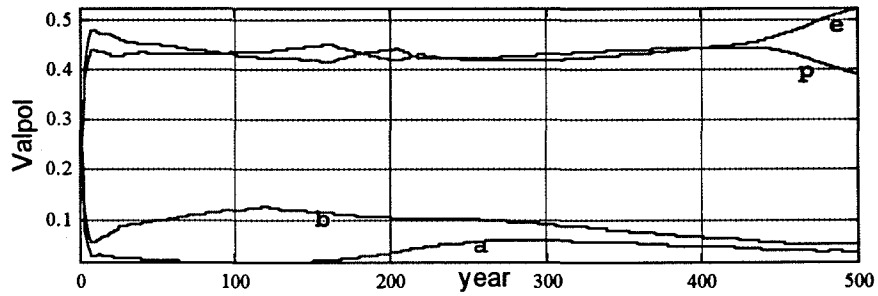

Fig.3

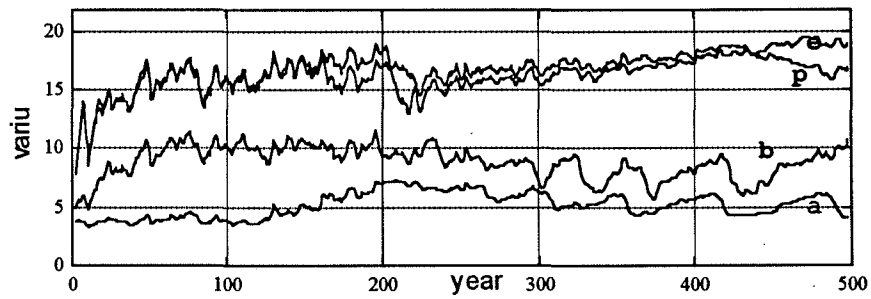

Fig.4

Fig.3: public savings (*Valpol*).
Fig.4: per-capita production factor (*variu*).

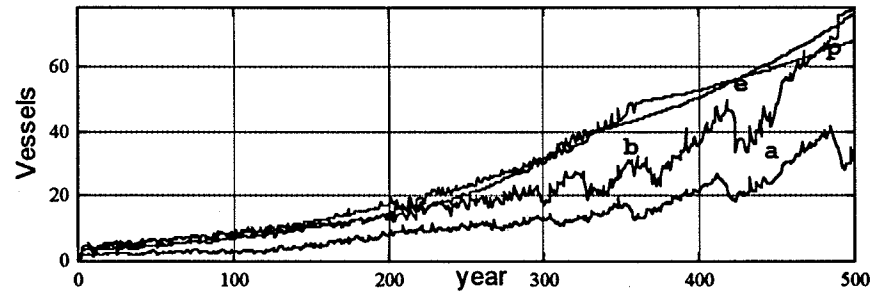

Fig.5

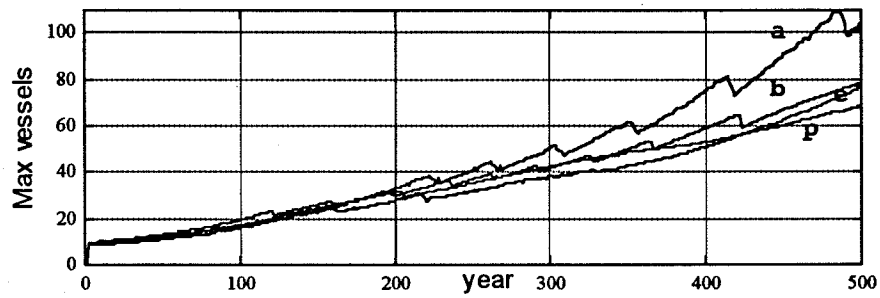

Fig.6

Fig.5: number of line vessels engaged in seasonal warfare .
Fig.6: maximum number of line vessels which may be rigged.